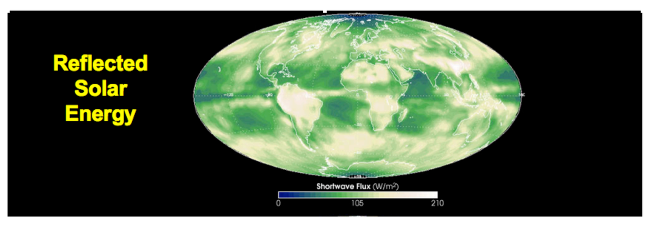
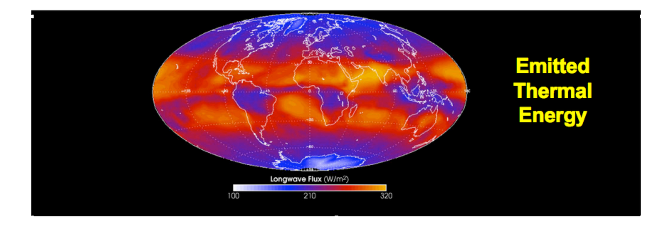
- CERES Measurements -
Continuation of the Earth Radiation Budget Climate Data Record





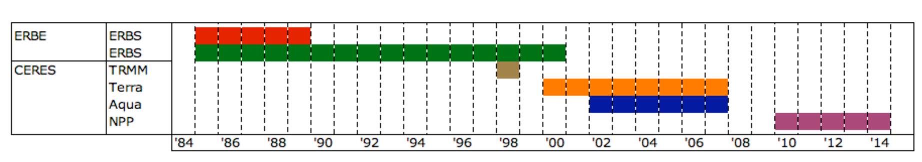
ERBE/CERES Heritage at NASA Langley Research Center

LARC has demonstrated scientific leadership for over 2 decades

Integrated lifecycle capabilities
- Instrument Design, Fabrication, Assembly, Test, Mission Operations
- Algorithm Design, development and verification
- Data production, Archival and Distribution

Centrally located team with national, international, government and university collaborators

LaRC ERB Climate Data record spans 23+ years



Radiometric Performance Requirements

CERES is defined as a class 'B' Mission

5-year design Lifetime

Spectral Regions	Solar		Terrestrial		Atmospheric Window
Wavelengths	0.3 - 5.0 µm		5.0 - 200 µm		8 - 12 µm
Scene levels	<100 w/m²-sr	>100 w/m²-sr	<100 w/m²-sr	>100 w/m²-sr	All Levels
Accuracy Requirements	0.8 w/m²-sr	1.0 %	0.8 w/m²-sr	0.5 %	0.3 w/m²-sr
SOW Stability Requirements		< 0.14%/yr		< 0.1%/yr	
Climate Stability Goals		< 0.6 w/m²/dec < 0.03 %/yr		< 0.2 w/m²/dec < 0.02%/yr	

- **Requirements for CERES are more stringent than ERBE's by a factor of 2**
- **Requirements per Ohring et. al. are more stringent than CERES by a factor of 3-5**

Calibrate, Calibrate, Calibrate….

Path to ERB CDR Continuity

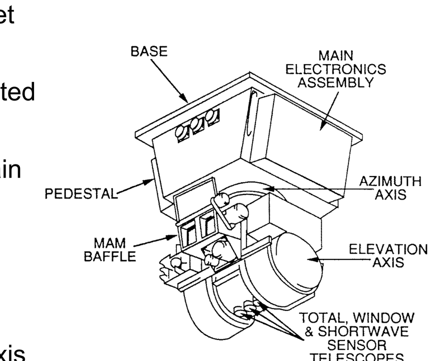
Capability	FM-5	FM-6	CERES Follow-on
Flight Software	Bug fixes, minimal functionality improvements	Bug fixes, minimal functionality improvements	Bug fixes, Full functionality improvements
New Solar Calibration MAM		Yes + enhanced screening	Yes + enhanced screening
Shortwave Internal Cal Source Upgrade*		Minimal Spectral Capability	Multi-spectral Capability
Replace 8-12 micron Channel		5 - 100 Micron	5 - 100 Micron
New Detectors			Yes
"10 km" FOV**			Yes
Ground Calibration	Re-verify sources, revisit procedure	Re-verify sources, update procedures, upgrade data acquisition equipment, enhanced emphasis in SOW	Re-verify sources, update procedures, upgrade data acquisition equipment, enhanced emphasis in SOW

* Updated shortwave requirements based on improved understanding of reflected spectrum from CERES experience

** Nominal improved FOV, final requirement set as part of CERES follow-on instrument study

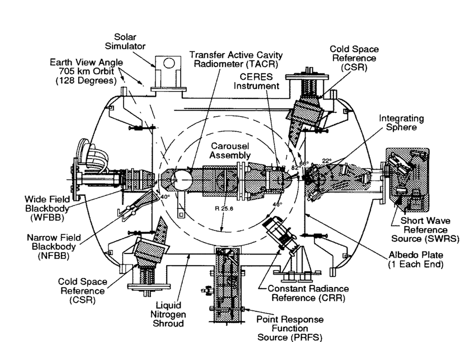
CERES Instrument

- Design is based upon the Earth Radiation Budget Experiment (ERBE) philosophy
- Instrument was designed, manufactured and tested by TRW (Redondo Beach, CA)
- Contains three sensor assemblies with cassegrain optics and thermistor bolometer detectors
- Sensors measure thermal radiation in the near-visible through far-infrared spectral region
- Three sensor channels coaligned and mounted on a spindle which rotates about the elevation axis
- Hemispherical sampling obtained with an azimuthal axis drive system
- Calibration Accuracy Requirements in SOW - 0.5% LW, 1.0% SW
- CDR Measurement Stability Goals - 0.02%/yr LW, 0.03%/yr SW



Radiometric Calibration Facility

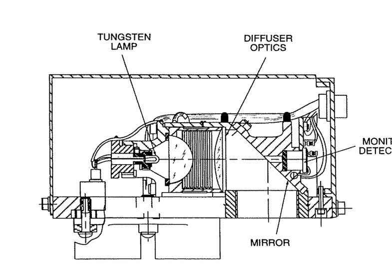
- Narrow Field of View Blackbody (NFBB) is primary standard (Emissivity of greater than 0.9999)
- 12.5 cm Wide Field of View Blackbody (WFBB)
- Cold Space Reference (CSR) blackbodies
- New SW reference source (SWRS) with minimum LW variations and better spectral characterization
- 5 cm i.d. integrating sphere with associated optics
- Cryogenically cooled Transfer Active Cavity Radiometer (TACR)
- Point Response Function characterization source
- Constant Radiance Reference to determine scan dependent offsets
- Earth infrared radiation simulators
- Liquid nitrogen cooled shroud wall



CERES FM6 Onboard SW Calibration Equipment

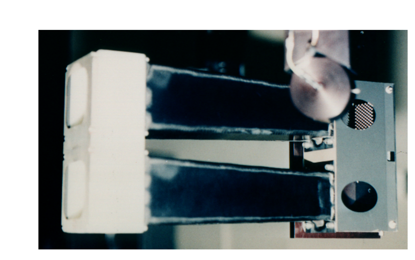
Shortwave Spectral Internal Module (SSWIM)

- Either lamps with spectral filters or a series of monochromatic sources
- Ability to vary strength of source preserved
- Contains independent monitoring of source output
- Design specification is 0.1% stability over 5-year mission
- Designed primarily to spectrally resolve changes in optical transmission



Mirror Attenuator Mosaic (MAM) Solar Diffuser

- Solar Diffuser plate attenuates direct solar view (~5800K Spectrum)
- MAM is currently a Nickel substrate with Aluminum coated spherical cavities or divots
- Provides a Relative calibration of the Shortwave channel and the SW portion of the Total channel
- Designed to provide a long-term on-orbit SW calibration source.



CERES Flight Schedule

Spacecraft	Instruments	Launch	Science Initiation	Collected Data (Months)
TRMM	PFM	11/97	1/98	9
Terra	FM1, FM2	12/99	3/00	100 +
Aqua	FM3, FM4	5/02	6/02	75 +
NPP	FM5	June 2010	-	-
NPOESS C1	***FM6***	***January 2013***	-	-
NPOESS C3	***CERES Follow-on***	***January 2018***	-	-

30 + Instrument Years of Data

Cal-Val Approach

Pre-Launch
- **Implement a rigorous & thorough ground calibration/characterization program**
- **Cal/Val role must be prominent in original proposal and SOW**
- **System level characterization is typically last test performed prior to delivery of the instrument**
- **Cost and schedule constraints typically drive programs at that point**

Post-Launch
- **Implement a protocol of independent studies to characterize on-orbit performance**
- **Studies should cover all spectral, spatial and temporal scales as well as data product levels**
- **Continuous development of new validation studies**

Data Product Release Strategy
- **Develop a logical and well understood approach to data release.**
- **Minimize the number of Editions/Versions of Data**
- **Utilize Data Quality Summaries for the community**

Lessons Learned / Future Direction

In the future CERES will fly in a single orbit with one instrument per spacecraft, eliminating key Direct Comparison validation capabilities…

Programmatic Implementation
- Increase weighting/influence of Radiometric Performance in cost/schedule trades
- Maintain positive/open relationship with hardware provider. Avoid 'Us' vs. 'Them' mentality.
  - *LaRC/NGST Team has proven track-record and experience*

Ground Characterization Procedures
- Re-verify traceability of calibration targets
- Establish collaborations with NIST, other international agencies
- Implement automated Data Acquisition System on Calibration Chamber

Operational Mode
- Do not point optics in 'forward' looking direction
  - *Strong Correlation to spectral darkening of SW channel optics*

Onboard Calibration Hardware
- Provide additional SW spectral characterization capability
  - *Stringent measurement requirements demand SW spectral capabilities*

Handling Procedures
- Minimize possibility of contamination
- Develop Inspection and cleaning procedures

Measurement to CDR

Does CERES measure Climate Data Records directly?

No, CERES measures instantaneous TOA broadband radiances

SW channel - Reflected Solar

TOT channel - Reflected Solar + Emitted Thermal

LW channel - Emitted Thermal

How do we get CDR's from instantaneous Radiance measurements?

Thermal Energy → Electrical Signal → Radiance → TOA flux → Surface and Atmospheric Flux → Gridding → Spatially Averaged → Temporal Interpolation → Temporal Averaging

In addition to CERES instrument data, this process requires:

- Cloud Imager Data
- Aerosol Optical Depth
- Atmospheric State Data
- Surface Temperatures
- Geostationary imager data for diurnal interpolation

High level of data fusion; up to 11 instruments on 7 spacecraft all integrated to obtain climate accuracy in TOA to surface fluxes ~8-dimensional radiative assimilation

CERES/EOS Edition2 Cal-Val Protocol

		Product	Spatial Scale	Temporal Scale	Metric	Spectral Band
On-Board	Internal BB	Filtered Radiance	N/A	N/A	Absolute Stability	TOT, WN
	Internal Lamp	Filtered Radiance	N/A	N/A	Absolute Stability	SW
	Solar	Filtered Radiance	N/A	N/A	Relative Stability	TOT, SW
Vicarious	Theoretical Line-by-Line	Filtered Radiance	> 20 Km	Instantaneous	Inter-Channel Theoretical Agreement	TOT, WN
	Unfiltering Algorithm Theoretical Validation	N/A	N/A	N/A	N/A	TOT, SW, WN
	Inter-satellite (Direct Comparison)	Unfiltered Radiance	1-deg Grid	1 per crossing	Inter-Instrument Agreement, Stability	TOT, SW, WN
	Globally Matched Pixels (Direct Comparison)	Unfiltered Radiance	Pixel to Pixel	Daily	Inter-Instrument Agreement	TOT, SW, WN
	Tropical Mean (Geographical Average)	Unfiltered Radiance	20N – 20S	Monthly	Inter-Channel Agreement, Stability	TOT, WN
	DCC Albedo	Unfiltered Radiance	>40 Km	Monthly	Inter-Instrument agreement, Stability	SW
	DCC 3-channel	Unfiltered Radiance	>100 Km	Monthly	Inter-Channel consistency, stability	TOT, SW
	Time Space Averaging	Fluxes	Global	Monthly	Inter-Instrument Agreement	LW, SW
	Lunar Radiance Measurements	Filtered Radiance	Sub Pixel	Quarterly	Inter-Instrument Agreement	LW, SW, WN

Science Rationale for FM6 Improvements

30 years of operational experience with CERES flight hardware demonstrates achieving the ERB CDR stability goal of 0.5 Wm^{-2} $decade^{-1}$ (0.3% $decade^{-1}$) requires…

- **Upgraded ground calibration/characterization**
  - ⇒ **Enhanced Ground Calibration: Re-verify sources, update procedures, upgrade data acquisition equipment, enhanced emphasis in SOW.**
- **Upgraded on-orbit calibration monitoring capabilities**
  - ⇒ **New solar calibration Mirror Attenuator Mosaic (MAM) to monitor SW channel gain change. Enhanced screening to ensure best MAM quality.**
  - ⇒ **Add onboard calibration source capable of quantifying spectral changes in the SW channel throughout the mission.**
- **Increased redundancy in sensors**
  - ⇒ **In the future there will only be a single CERES sensor flying on a single spacecraft with minimal overlap between successive flights.**
  - ⇒ **Convert CERES Window channel to a Longwave channel via an optical filter change; provides redundancy to overcome the loss of any single channel, SW could be inferred from TOT minus LW if SW channel fails, and both SW and LW would still be obtained if the TOT channel fails.**